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THE RECOVERY OF LAKE LIEVESTUOREENJÄRVI

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A sulphite pulp mill discharging effluent into Lake Lievestuoreenjärvi was closed down in 1967 and reopened in 1971. During the first year after closure the concentration of organic matter in the lake water reduced to about one half of its former level, which was faster than could be accounted for by the dilution rate in this lake. Despite this, the level of oxygen in the water remained low. Subsequent reduction in the organic matter content corresponded to the calculated rate of dilution, and during this period oxygen concentration improved to a fair level. This indicated that the still considerable quantity of organic matter remaining in the lake decomposed only slowly in the conditions prevailing. A clear diversification in phytoplankton composition occurred during the period when the factory was not in operation, although species favouring polluted waters were dominant throughout. The occurrence maximum of benthic fauna progressed from the littoral to the profundal layer. After the reopening of the factory the quality of the lake water decreased within one year.

Index words: pulping effluents, self purification.

1. INTRODUCTION

The aim of this work was to investigate the recovery of the lake after the closure of the polluting factory.

The pulp mill Haarlan Selluloosa, situated on the shore of Lake Lievestuoreenjärvi, ceased its operations in spring 1967 after a production run of 40 years. The factory produced birch sulphite cellulose at a capacity of around 46 000 t/d. The waste waters were not collected and about half of the loading content, 30 t/d BOD_5, was discharged to the lake. The factory was reopened in winter 1971, after which all the effluents were led into the lake with the result that the loading was greater than before the closure (50 t/d BOD_7). After the introduction of partial recovery of waste waters in winter 1973 the loading decreased by about 15 t/d BOD_7.

The surface area of Lake Lievestuoreenjärvi (Fig. 1) is 41.7 km^2 and its volume $422 \cdot 10^6 m^3$. The flow of water into the lake has been estimated to be on average (m^3/s):

1967	1968	1969	1970	1971	1972	1973	1974
4.2	4.0	3.7	3.4	4.0	3.8	3.5	5.7

The calculated residence time is thus 4 years (Häikiö 1970).

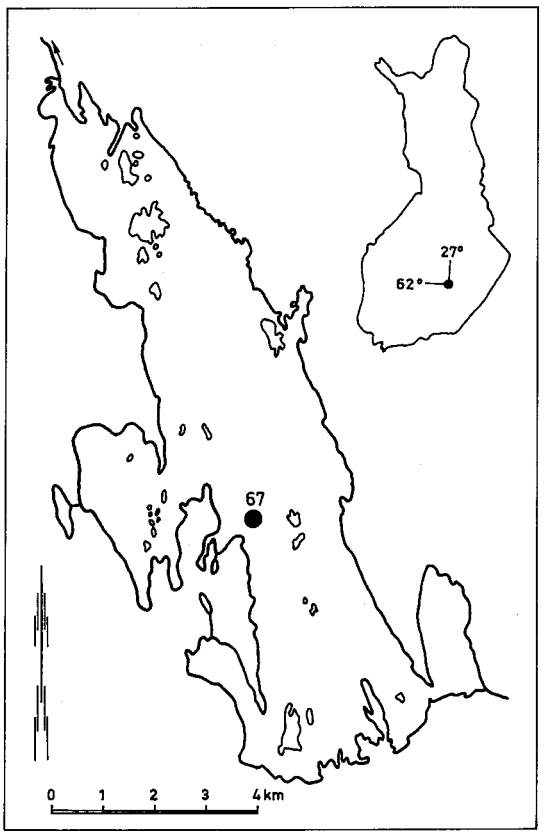

Fig. 1. Lake Lievestuoreenjärvi • 67 Sampling site.

2. DISCUSSION

2.1 Physical-chemical observations

Monitoring of water quality was based on observations made in the main trough of the lake.

The dominant effect of the pulping effluents to water quality is to be seen rather high COD-value after the closure of the factory (Table 1). The difference in concentrations between the upper and lower water levels was at first considerable (Fig. 2), but later decreased. Thus the levels of both COD and organic carbon decreased in slightly over one year to about half their original values, which was clearly faster than could be predicated on the basis of the dilution rate. After this initial rapid decrease, the subsequent rate of decrease corresponded approximately to the dilution rate until the reopening of the factory. The minimum value of COD, 22 mg/l, was still rather high, being 1/4 of the original value and 2/3 of that which would be calculated on the basis of dilution alone. After the reopening of the factory the COD increased rapidly to as high as 100 mg/l. The effect of burning of the waste liquer appeares as diminishing COD-value (Fig. 2).

The lignin content also decreased in slightly over one year to about half its value before closure (Fig. 3), after which the decrease corresponded approximately to the dilution rate.

Table 1. Average concentrations of some indicator parameters of water quality during the period 1967–1974. A = first half-year; B = second half-year.

Year		Specific conductivity, mS/m	COD mg/l	Water Colour mg/l Pt	NaLS mg/l	Org.C mg/l	Tot.P µg/l	Tot.N µg/l	Mn mg/l	Fe mg/l
1967	A	16.0	85	270	-	75	50	800	3.0	2.3
	B	15.0	75	250	30	50	50	800	-	-
1968	A	14.0	55	210	-	40	50	900	2.6	2.2
	B	13.0	42	240	11	32	50	800	-	-
1969	A	11.5	35	180	8	-	55	900	1.6	3.0
	B	11.0	29	180	6	20	50	700	-	-
1970	A	10.5	25	165	4.5	19	55	800	0.9	2.5
	B	10.0	23	135	3.5	18	45	700	0.7	2.4
1971	A	9.5	22	125	3.0	18	35	600	0.5	2.4
	B	10.0	34	-	18	22	45	700	0.5	1.8
1972	A	10.5	60	140	35	40	50	600	1.3	1.8
	B	12.0	75	180	55	-	55	700	1.4	2.0
1973	A	13.5	100	190	68	65	45	700	1.4	1.8
	B	13.5	89	205	52	-	65	700	1.4	2.0
1974	A	14.7	84	220	42	55	65	700	1.5	2.2
	B	14.3	77	230	30	-	74	600	1.4	2.3

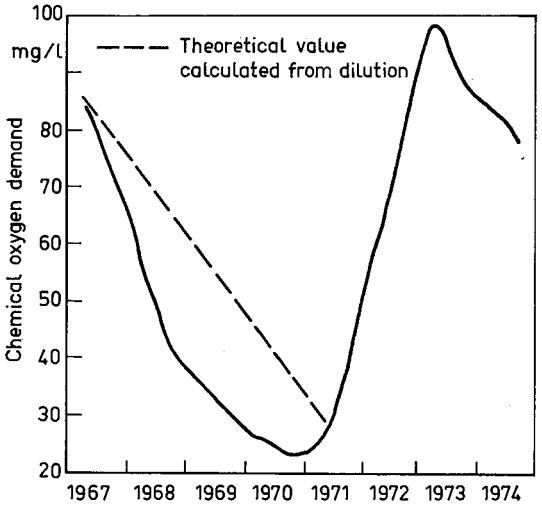

Fig. 2. COD in the years 1967–1974.

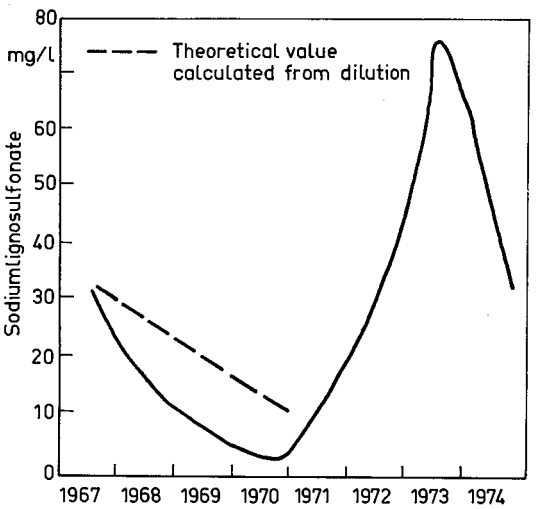

Fig. 3. NaLS in the years 1967–1974.

At the end of the none-operational period the lignin content had decreased to 3 mg/l, which was 1/4 of the value calculated from the dilution rate. In comparison with the COD value, the lignin content decreased manyfold from its initial level. After the reopening of the factory the concentration of NaLS increased to a very high level, approximately 70 mg/l, and decreased after the introduction of burning of the waste liquor considerably faster than COD.

Water colour was found to decrease (Fig. 4) during the none-operational period to below half its original value, although even the minimum value was rather high, 125 mg/l Pt. Water colour did not decrease in proportion to the measured chemical parameters of organic matter, because high concentrations of iron and manganese also increased the values obtained for water colour. Similarly, the Secchi depth remained low throughout the none-operational period, with an increase of from one to almost two metres. After the reopening of the factory the water colour value almost doubled and the Secchi depth again decreased to slightly under one metre.

Immediately after the closure of the factory the oxygen conditions (Fig. 5) were very poor. The bottom layers were anaerobic and even in the surface water the oxygen content was only 50 % of the saturation level, decreasing to below 10 % during the spring turnover. Oxygen levels did not improve notably during the first summer after closure, but by the following winter the situation had greatly improved, with totally deoxygenated water being found only in the deepest parts of the major trough. In summer 1968 oxygen levels were much improved over those of the previous summer. Oxygen concentrations in the bottom and surface layers were 30 % and 70 % of the saturation value, respectively. In the following winter the situation was similar to that of the previous winter, while in 1969 the oxygen concentration in bottom waters was still only about 30 % of saturation. In 1970 some improvement was noted, with a summer oxygen concentration of over 50 % in the bottom layers.

Oxygen levels in the lake changed in accordance with the measured parameters of organic loading. Immediately after closure of the factory the water still contained large amounts of readily decomposable organic matter, with a resultant oxygen deficit. When this fraction began to decrease, oxygen consumption also decreased. At the end of the none-operational period the water still contained considerable amounts of slowly decomposing organic matter. This did not however prevent a slow increase in oxygen concentration, although the final values before reopening of the factory were still far below those occurring in lake water in a natural state.

After the reopening of the factory the lake was subjected to an almost doubled loading compared with than of the earlier period of operation. This resulted in a clear reduction in oxygen concentrations as early as the following summer, when the concentration in the bottom

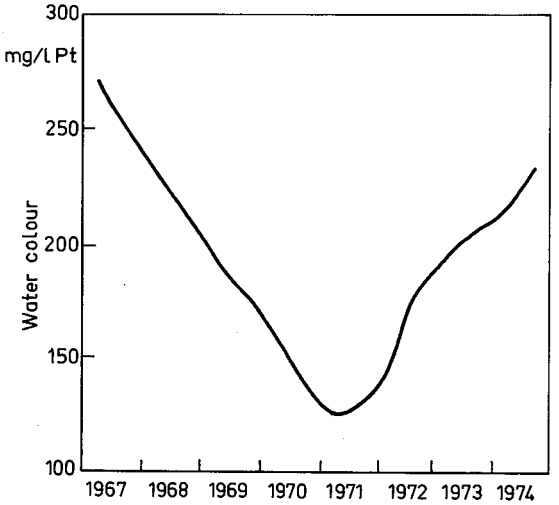

Fig. 4. Water colour in the years 1967–1974.

layers was only 30 % of saturation. By 1972 the situation was at least as poor as before the closure, with oxygen concentrations om the surface water in summer being only 20 %.

Decrease in electrical conductivity, which immediately after the closure was 16.5 mS/m, followed the calculated dilution rate of the lake. This result was as anticipated, because most of the salts affecting conductivity are not adsorbed biologically. At the end of the none-operational period the measured conductivity (9.5 mS/m) was still about double the value estimated for water in a natural state (about 4.0 mS/m). When the loading was resumed the conductivity increased markedly almost to its earlier value. The reduction in overall loading caused by the introduction of burning of the waste liquor did not affect the conductivity.

Immediately after the closure of the factory the iron concentration in the lake water was 2.3 mg/l. During the operation of the factory it is likely that iron was precipitated as sulphide due to high concentrations of H_2S and a suitable

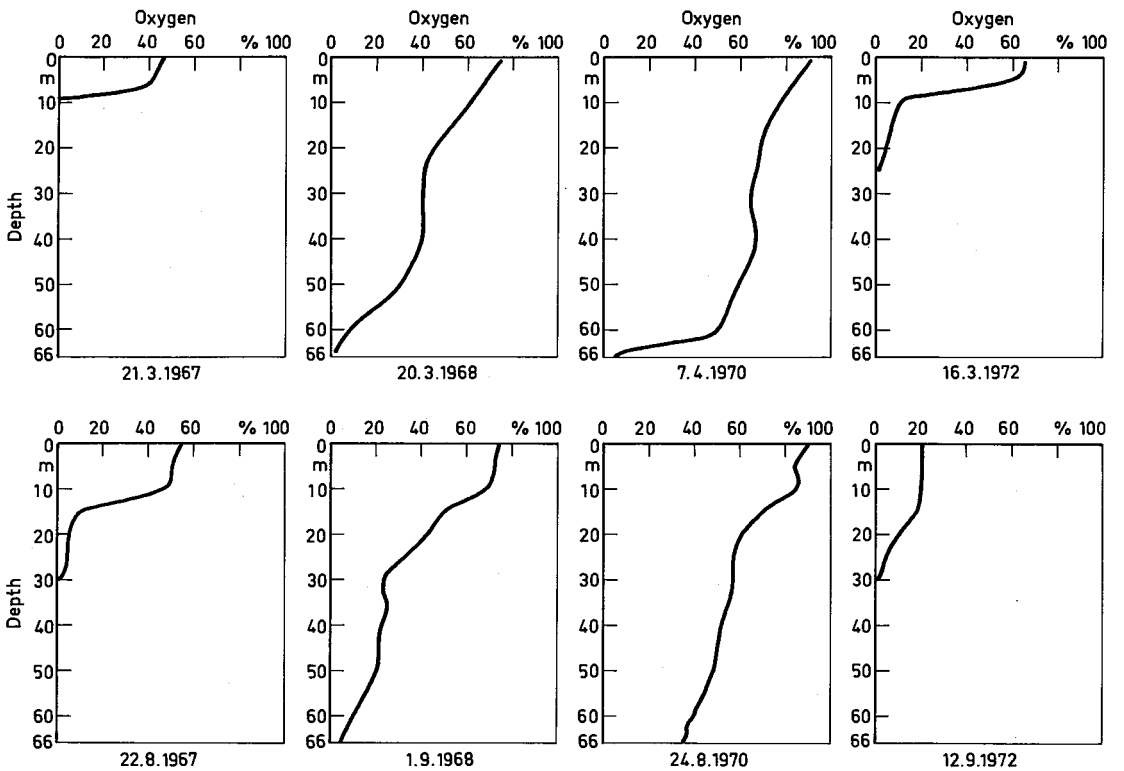

Fig. 5. Oxygen in Lake Lievestuoreenjärvi during 1967–1972.

pH. With improved levels of dissolved oxygen the iron was no longer sedimented, and iron concentrations during the none-operational period were in fact found to increase.

Manganese is not precipitated in the form of sulphide as easily as iron. Immediately after manganese concentration of the lake water was high, around 3 mg/l. With improved oxygen levels manganese was precipitated and its concentration in the water decreased more rapidly than could be accounted for by the dilution rate. By the end of the none-operational period the manganese concentration was only 0.5 mg/l, but after the recommencement of loading it increased again to 1 mg/l.

The nitrogen concentration in the lake water decreased somewhat during the none-operational period, although it was still high (600 µg/l) by comparison with the estimated value for lake water in a natural state. The phosphorus concentration was also high at the beginning of the none-operational period, 50 µg/l. Phosphorus concentration also showed a slight decrease, but remained many times greater than the value for lake water in a natural state. This was probably due in part to the fact that the lake receives untreated sewage from almost 2 000 inhabitants. The nitrogen-phosphorus ratio was around 16:1 throughout the none-operational period and reduced to 10:1 in surface water layers after the reopening of the factory.

2.2 Biological observations

As a result of the effluents of the cellulose factory the species composition of phytoplankton in the lake water was very limited (Westerling 1961). The dominant organisms in the low total biomass (c.f. Laaksonen 1965) at the beginning of the none-operational period were *Cryptomonas* sp. (54 %) and *Flagellata* sp. (45 %). By the late summer of 1967 the species number had increased noticably (Table 2), but the total biomass was still low. In the subsequent summer seasons the biomass also increased and the species composition diversified. In addition to the organisms mentioned above the following species were also present in large amounts: *Tabellaria fenestrata* var. *asterionelloides* and *Closterium acutum* var. *variable*. According to Järnefelt (1961) these species occur mainly in a biotope containing effluents. Many other of the species observed in fairly large numbers also belonged to this group

Table 2. Phytoplankton composition during the years 1967–1970.

Date	Species number	Biomass (fresh weight) mg/l
21.6.1967	19	0.07
22.8.1967	28	0.14
12.6.1968	26	0.56
26.6.1968	29	0.23
7.8.1968	37	0.65
11.9.1968	39	0.30
26.6.1969	36	0.34
25.8.1969	41	2.15
25.6.1970	21	1.09
24.8.1970	37	0.78
4.9.1970	32	0.23

on were indifferent. Even at the end of the none-operational period the species composition was still indicative of the effects of pollution.

With the recommencement of loading the species composition again altered, becoming similar to that of the original polluted lake. In spring 1973 the dominant species were *Flagellata* sp. and *Cryptomonas* sp. Biomass varied between 0.02 and 0.74 mg/l, with an average value of 0.29 mg/l. Primary productivity also varied greatly, between 2 and 571 mg/m^3 C, with a mean of 145 mg/m^3 C. In *in situ* estimations the photosynthesis took place in the water surface layer. The great variation recorded is typical for polluted waters (Heinonen 1972, Granberg and Holopainen 1973).

At the beginning of the none-operational period benthic fauna was found most abundantly in the littoral zone (Fig. 6), and its number increased with distance from the factory. Very few benthic organisms were found in the profundal zone near the factory, although their number also increased further away. The dominant organisms were *Chironomidae*, with some *Chaoborus* and *Oligochaeta*. After two years a distinct change was observed in the distribution of benthic fauna, with clear reduction in numbers in the littoral zone and increase in the deeper layers. A similar situation was also recorded in 1970. In some areas benthic fauna was extremely abundant and some other groups of organisms also began to make an appearence. The decrease in numbers recorded in the littoral zone may have been due to nutrient reduction and increase in the fish population. The increased dissolved oxygen levels made possible the utilization of the profundal zone by benthic fauna.

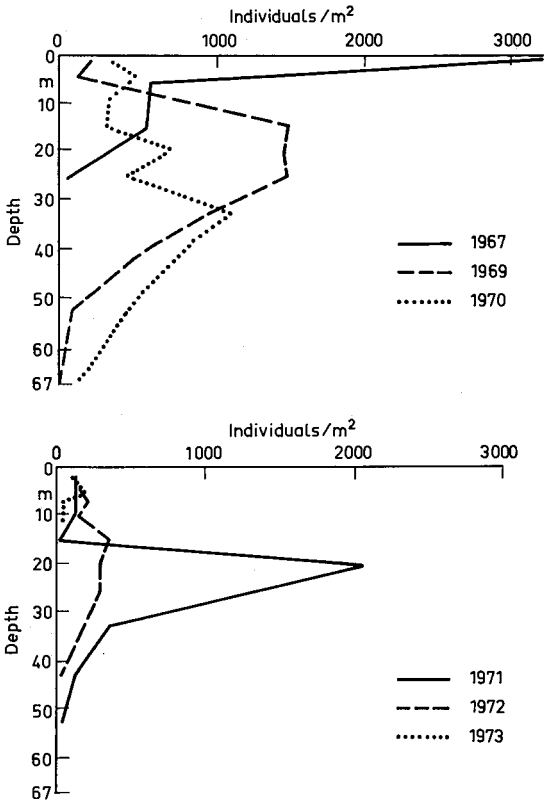

Fig. 6. Benthic fauna in Lake Lievestuoreenjärvi.

After the resumption of loading a marked decrease in the numbers of benthic fauna was recorded during the following summer near to the factory. During the succeeding year this tendency continued and increased in the lower water levels. By 1973 benthic fauna was found only in small numbers in the littoral zone, while the species which had made their appearence during the none-operational period were no longer encounted.

SUMMARY

A sulphite cellulose factory which for 40 years had discharged effluent to Lake Lievestuoreenjärvi was closed down in 1967 and reopened in 1971. Before the closure the lake was classified as polluted. At the beginning of the none-operational period the amount of readily decomposable compounds decreased clearly faster than could be accounted for by the dilution rate of the lake. Later, the rate of decrease in the amount of organic matter slowed down to that corresponding to dilution.

The level of dissolved oxygen increased considerably one year after the disappearence of the easily decomposable material, and by the end of the none-operational period oxygen concentrations had reached a fair level. Although overall water quality improved considerably during the 4 years before reopening of the factory, it was still very far from the quality of lake water in a natural state.

At the beginning of the none-operational period the phytoplankton was very limited, being composed mainly of only two species, while the total biomass was low. The species composition diversified considerably in the succeeding years, but the dominant species were still a rather small number of organisms favouring, or at least tolerating, the effluents of cellulose pulping factories.

Benthic fauna was composed mainly of Chironomidae. During the none-operational period the benthos maximum moved from the littoral to the profundal zone with improvement in dissolved oxygen levels.

After the resumption of loading the indicators of cellulose effluents increased rapidly. Oxygen levels decreased within one year to the values measured before the closure of the factory, while both phytoplankton and bethic fauna became rapidly empoverished to their earlier levels.

The results of this investigation indicated that lake water badly polluted by wastes of the pulping industry may still recover if the loading is discontinued. In the present case the situation improved considerably within one residence time (4 years), after which the lake contained only slowly decomposable organic material and oxygen concentrations in the water were considerably increased. However, the lake water still had a very high nutrient potential, the significance of which in the recovery process remained undetermined.

LOPPUTIIVISTELMÄ

Lievestuoreenjärveä noin 40 vuotta kuormittanut sulfiittiselluloosatehdas suljettiin vuonna 1967 ja

otettiin uudelleen käyttöön vuonna 1971. Tutkimuksessa seurattiin tämän likaantuneen järven veden laadun muuttumista.

Tehtaan sulkemisen jälkeen helposti hajoavien yhdisteiden määrä väheni vedessä selvästi nopeammin kuin pelkän laimenemisen mukaisesti oli laskettu. Myöhemmin orgaanisen aineen väheneminen tapahtui laimenemisen mukaisesti. Vastaavasti happitilanne parani vuoden kuluessa huomattavasti. Puhtaan luonnonveden arvoja ei kuitenkaan saavutettu koko seisokkiaikana.

Tehtaan sulkemisen jälkeen kasviplanktonin biomassa oli alhainen ja muodostui pääasiassa vain kahdesta lajista. Lajikoostumus monipuolistui huomattavasti seisokin aikana, joskin valtalajeina säilyivät edelleen jätevesiä suosivat tai sietävät lajit.

Pohjaeläimistö koostui pääosin Chironomidae-lajeista. Seisokin aikana eläimistön esiintymismaksimi siirtyi parantuneen happitilanteen ansiosta litoraalista profundaaliin.

Tehtaan lähdettyä uudelleen käyntiin jätevesien vaikutukset näkyivät nopeasti. Happitilanne heikkeni vuodessa ennen tehtaan sulkemista havaitulle huonolle tasolle. Vastaavat muutokset tapahtuivat myös kasviplanktonissa ja pohjaeläimistössä.

Tämän tutkimuksen tulokset osoittivat pahoin pilaantuneen järven elpyvän suhteellisen nopeasti, mikäli kuormitus kokonaan lopetetaan. Huomattava paraneminen tapahtui tässä tapauksessa yhden viipymäkauden (4 vuotta) aikana. Nopeasti hajoava orgaaninen aines oli hajonnut ja happitilanne oli suhteellisen hyvä. Vedessä oli kuitenkin vielä hyvin runsaasti ravinteita, joiden merkitys järven elpymisen yhteydessä jäi tarkemmin selvittämättä.

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